Errors Due to the Reflectivity of Calibration Targets

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I. INTRODUCTION

- NIST microwave radiometry effort
  30⁺ years experience in noise and antenna metrology at NIST; recently began doing remote-sensing radiometry, combining the two.
- Developing microwave radiometry cal stds:
  - E.g., Randa *et al*., "Standard Radiometers and Targets for Microwave Remote Sensing," IGARSS-04
- Related issue is the (non-ideal) reflectivity of calibration targets. This work describes:
  - Causes
  - Expressions (approximate) for T_B error introduced
  - Measurement examples

- Calibration targets close to the sensing antenna:
  - linear radiometers need ≥ two standards for calibration.
  - satellites: cold sky, if possible (far-field)
  - otherwise: hot & cold targets (near-field)
  - Scene is always far-field
- Near-field targets introduce two general types of error in a total-power radiometer:
  - Antenna+target affects antenna pattern, directivity (ignore)
  - $\Delta\Gamma$ at antenna output due to non-ideal target (this work):
    - Difference in M (mismatch factor) for target, scene
    - Difference in system F and G_{av} " " "

OUTLINE

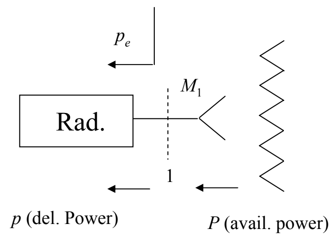
- Theoretical Framework
  - Radiometer equation (common approximation)
  - Modifications for $\Delta\Gamma$ effects
  - T_B uncertainty estimates
- Measurements
  - AIMR radiometer, antenna & target (37 GHz)
  - NASA target & NOAA antenna (54 GHz)
- Numerical estimates
- Summary

II. THEORETICAL FRAMEWORK

Radiometer equation:

$$p_1 = M_1 P_1 + p_{e,1}$$

$$M_1 = \frac{\left(1 - |\Gamma_{ant}|^2\right)\left(1 - |\Gamma_r|^2\right)}{|1 - \Gamma_{ant}\Gamma_r|^2}$$



•View cal targets h and c, unknown scene x.
•If M_1 and $p_{e,1}$ are the same for all three cases (h, c, and x) then

$$(T_x - T_c)_0 = \frac{(p_x - p_c)}{(p_h - p_c)}(T_h - T_c)$$

…but what if M_1 and $p_{e,1}$ are *not* the same for all three cases?

Modified Radiometer Equation

- Including the effect of differences in M_1 and $p_{e,1}$ for the three cases:

Mismatch changes

$$T_x - T_c = (T_x - T_c)_0 (1 + \delta_1) + \Delta_2 + \Delta_3$$

F_N and G_{av} changes

[Details described in upcoming TGARSS paper]

Useful approximations for $\delta 1$, $\Delta 2$ and $\Delta 3$:

- Assume antenna $\Gamma_h = \Gamma_c$
- Γ_∞ is refl. coeff. of ant. looking at distant scene
- Γ_r is refl. coeff. of radiometer at plane 1

$$\delta_1 \approx 2\,\mathrm{Re}\left[(\Gamma_r - \Gamma_\infty)\Delta\Gamma\right],$$
$$\Delta_2 \approx 2T_c\,\mathrm{Re}\left[(\Gamma_r - \Gamma_\infty)\Delta\Gamma\right] = \delta_1 T_c,$$
$$\Delta_3 \approx 2X_1\,\mathrm{Re}\left(\Gamma_\infty \Delta\Gamma\right) + 2\,\mathrm{Re}\left(X_{12}\Delta\Gamma\right),$$

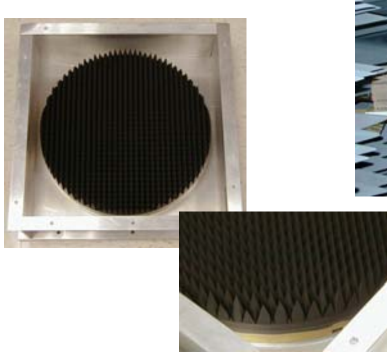
where X_1 and X_{12} are noise parameters of the radiometer.
So, we need to know or estimate Γ_r, Γ_∞, $\Delta\Gamma$, X_1, and X_{12}.

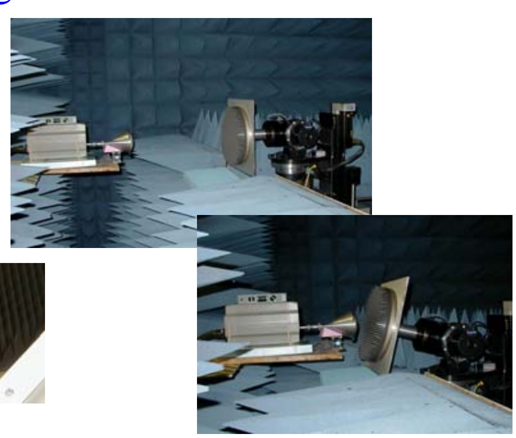
Measure with ANA

III. MEASUREMENTS

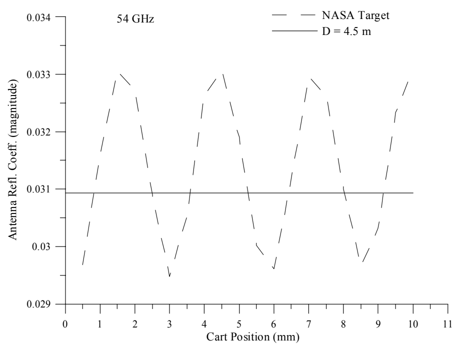
- Measured Γ_c, Γ_∞ (thus $\Delta\Gamma$) with ANA for several combinations of antenna and target.

NASA target and NOAA antenna

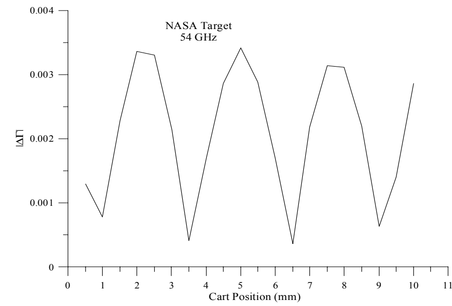




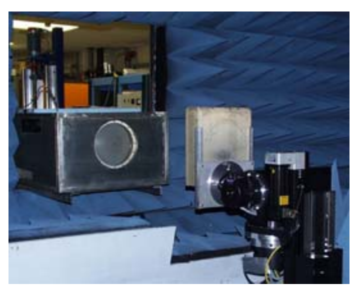
NASA target,
NOAA antenna
Γ_c , Γ_∞

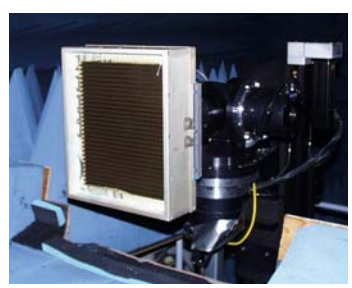


$\Delta\Gamma=\Gamma_c - \Gamma_\infty$



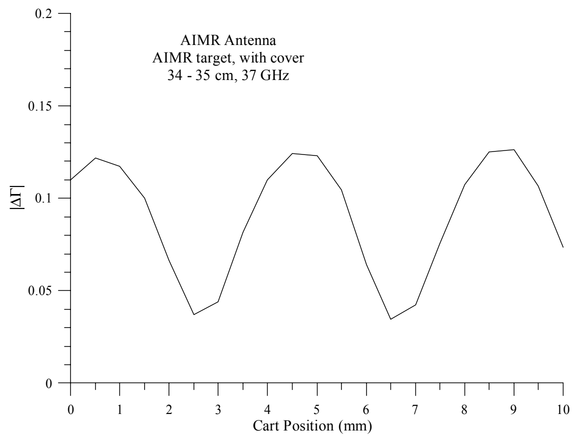
AIMR Antenna & Target





AIMR target and antenna

$\Delta\Gamma = \Gamma_c - \Gamma_\infty$



Reciever Noise Parameters

- Use Meys' method to measure X_1 and $|X_{12}|$ at AIMR receiver input at 37 GHz:
  - $X_1 \approx 223$ K
  - $|X_{12}| \approx 37.6$ K

- For a total-power radiometer with an input isolator, $X_1 \approx T_I, \quad X_{12} \approx -T_I S_{11}^I,$

$$\Delta_2 + \Delta_3 = 0$$

$\rightarrow$ Only remaining error is δ_1

IV. NUMERICAL ESTIMATES

- Total error introduced by using simple form of radiometer equation depends on Γ_r; assume it's 0.

$$\Delta_{tot}^{(0)} \approx 2(X_1 - T_{x,0})\,\mathrm{Re}(\Gamma_\infty \Delta\Gamma) + 2\,\mathrm{Re}(X_{12}\Delta\Gamma)$$

For actual rad., use $(\Gamma_r - \Gamma_\infty)$

- Standard uncertainty u given by

$$u_{tot}^{(0)} = \sqrt{\left\langle \left(\Delta_{tot}^{(0)}\right)^2 \right\rangle}$$

RMS over reasonable values of unknown parameters:

ant→target dist. $\angle X_{12}$-$\angle\Delta\Gamma$

$$= 2\left\{(X_1 - T_{x,0})^2 \left\langle (\mathrm{Re}(\Gamma_\infty \Delta\Gamma))^2 \right\rangle + \frac{1}{2}|X_{12}|^2 \left\langle |\Delta\Gamma|^2 \right\rangle \right\}^{1/2}$$

Uncertainties

- AIMR antenna & target, $T_{x,0}$ from 200 K to 300 K:

$$u_{tot}^{(0)} \approx \sqrt{2}\,|X_{12}|\,|\Delta\Gamma|_{RMS} \approx 5.2\,K$$

- Prior AIMR cal checks show agreement to within ~2 K
  - $|X_{12}|$ may be overestimated due to meas. time span
  - Spare feedhorn w/o reflector may differ from actual components
  - RMS value is an average; actual instrument is just one position

- Add input isolator with $|S_{11}|$=0.025; for $|T_{x,0} - T_a| \leq$50 K

$$u_{tot}^{(0)} \approx 1\,K$$

Uncertainties

- NOAA ant., NASA target, $T_{x,0}$ from 200 K-300 K:

$$u_{tot}^{(0)} \approx 0.0033 \left| X_{12} \right|$$

- $|X_{12}|$ could be 100 K or more, so uncertainty could be ≥ 0.3 K
  - Significant for some radiometers to be deployed in the next decade

- With an input isolator:

$$u_{tot}^{(0)} \approx 0.95\ K \times \left| S_{11}^{I} \right|$$

$$u_{tot}^{(0)} \leq 0.1 K$$

V. SUMMARY

- Considered error arising from difference in $\Gamma_{ant.}$ when viewing distant scene and nearby cal target
- Developed expressions for approximate T_B error; performed measurements enabling us to estimate u for representative cases
- For total-power radiometers w/o isolators, u can be several kelvins (tenths in good cases)
  - Sensitive to $\Gamma_{ant.}$, Γ_r, target reflectivity, rcvr X's, and **antenna-target spacing**
- Should measure (or estimate) Γ's and X's to estimate uncertainties
- Could correct for these effects w/full rad eq'n

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